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TRANSLATION

STRESS-RUPTURE STRENGTH OF STEEL IN LIQUID SODIUM CONTAINING OXYGEN

By

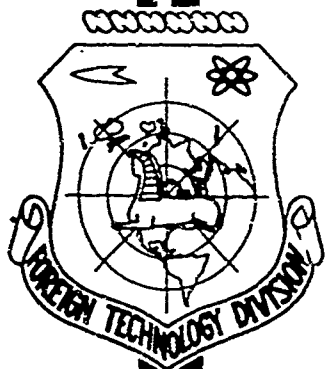
V. I. Nikitin

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

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STRESS-RUPTURE STRENGTH OF STEEL IN LIQUID SODIUM CONTAINING
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Page No. 613-617

STRESS-RUPTURE STRENGTH OF STEEL IN
LIQUID SODIUM CONTAINING OXYGEN

V. I. Nikitin

Results of testing chromium-nickel austenitic steel for stress-rupture strength at 700° in air and in sodium, containing 0.01 and 0.25 weight % O₂ are presented. The lowering of time prior to the rupture and increase in rate of creep of steel in sodium with 0.25% O₂ in comparison with an air medium is fixed. The observed effects are explained by corrosive and absorptive effect of the medium.

One of important problems, associated with use of sodium as heat-carrier, is question about the admissible oxygen content in it. Investigations of corrosion of steels in a liquid sodium have led to the conclusion that a concentration of oxygen in a liquid metal should not exceed 0.005 weight% [1-3]. This conclusion is founded on experiments in determining the rate of corrosion. At the same time it is noted that the high content of oxygen in sodium at temperatures higher than 550°C results in the embrittlement of steel [4-6]. In connection with this it was possible to expect that the effect of an admixture of oxygen in sodium into steel, being in a stressed state may cause its premature rupture. It is possible that these tests will show the necessity of maintaining the oxygen concentration in sodium at an even lower level than during corrosion tests.

To the investigation was subjected austenitic chrome-nickel steel (13.6% chrome 18.9% nickel), alloyed by tungsten (2.3%) and niobium (1.2%). The thermal processing of steel was performed according to the following method: hardening with 1,100° in water and tempering at 800° for 10 hours.

The effect of admixture of oxygen in sodium on stress-rupture strength was investigated in tubular machined specimens with the outside diameter 11 mm, the thickness of wall 0.5 mm and a rated length of 50 mm. The sodium during test was inside specimen. Filling up specimens with liquid metal was made in filtration-al installation. Contents of oxygen in sodium, filtered in this installation, amounted to 0.01 weight%. Pressurization of internal volume during test was attained by means of welding of a steel cork to the inlet of sample.

There were performed three series of tests for stress-rupture strength: Specimens of first series were tested without filling by sodium; the internal volume was filled with argon and was hermetically sealed by welding of cork. Specimens of second series were tested in sodium, containing 0.01% oxygen, specimens of third series -- in sodium with 1% oxygen. Increased content of oxygen in specimens of third series was attained by addition into each specimen of a calculated quantity of peroxide of sodium. Since equilibrium solubility of oxide of sodium in sodium at 700° is equal to 0.25 weight% [7], than medium in specimens of third series was two-phase. For removing contact of working surface of specimen with the oxide of sodium at first was made a filling of the specimen with sodium and then onto its surface was poured powder of peroxide of sodium. Full decomposition of peroxide of sodium into an oxide and oxygen occurs at 545° [8]. Consequently, at temperature of experiment (700°) specimens of third series actually tested the effect of liquid metal, containing the maximum possible at this temperature quantity of oxide of sodium (0.25%).

All tests for stress-rupture strength were made at a temperature 700° on

UDM-5 machines.

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4		4
3		3
2		2
1		1
0		0

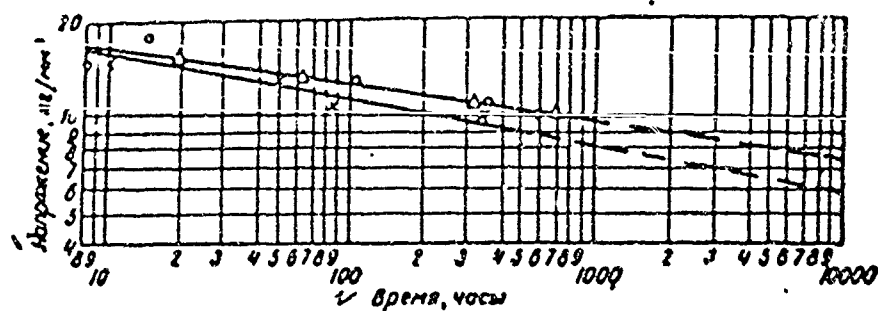


Fig. 1. Dependence of time prior to destruction on stress. * in air; O - in sodium with 0.01% oxygen; x - in sodium with 0.25% oxygen. 1) Stress kg/mm; 2) Time, hours.

Results of tests for stress-rupture strength in the form of a dependence of time prior to destruction on stress is shown in Fig. 1. From graph it follows that sodium, containing 0.01% oxygen, does not cause premature destruction steel in comparison with an air medium.

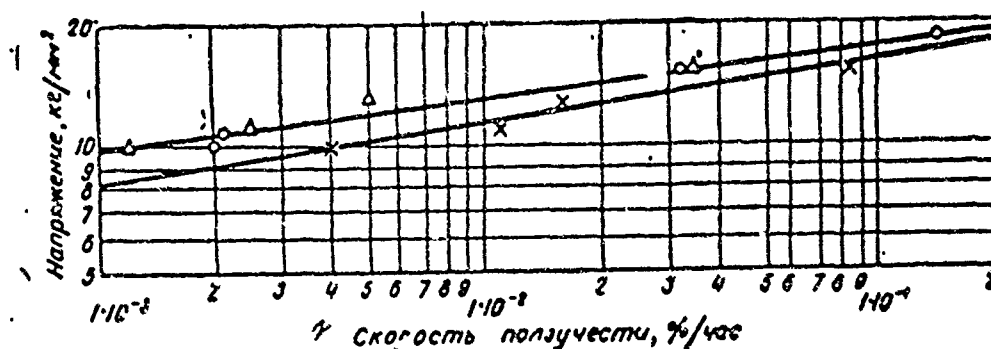


Fig. 2. Dependence of minimum rate of creep on stress effort. Designations the same as in Fig. 1. 1) Stress kg/mm²; 2) rate of creep, % hour.

Increase in contents of oxygen in sodium to 0.25% causes a lowering of stress-rupture strength of steel. However, the magnitude of lowering and with so high a concentration of oxygen in liquid metal is relatively small.

The elongation, aggregated by specimens during creep with the test in sodium and in air, is identical and is within the limits 1-5%.

Dependence of minimum rate of creep on stress is shown in Fig. 2. As can be seen, acceleration of creep, in comparison with air, is observed only in sodium with an admixture 0.25% oxygen. The greater is the increase in rate of creep

in sodium (comparatively with air) the lower is the stress and correspondingly the lower is the absolute value of rate of creep. With a rate of creep, equal to $1.10^{-4}\%$ hour, this increase is equal to 4.2.

A comparison of the average rates of creep in first and third periods and minimum rate of creep shows (Fig. 3) that steel is deformed in sodium with 0.25% oxygen with a higher rate, than in air during entire time of creep. And besides, along primary curve of creep occurs a continuous acceleration of the creep in comparison with air, that is

$$K_{\sigma_1} < K_{\sigma_{min}} < K_{\sigma_2} \cdot \left(K_{\sigma_{max}} \frac{\sigma_2^2}{\sigma_1^{2.038}} \right).$$

Analysis of microstructure of specimens after rupture showed following. The investigated steel was very inclined to intercrystalline failure to and without effect of the medium. Specimens, ruptured in air, have a greater, progressively increasing in time number of intercrystalline cracks, sometimes penetrating into specimen to a depth of ten grains. Specimens, tested in sodium with 0.01% oxygen, also are subjected to intercrystalline failure, but the cracks in them are scarcely larger, than those in specimens tested in air. In certain cases on the inner surface of specimen, contacting sodium during test, there were even fewer cracks, than on outer surface. The number of intercrystalline cracks in specimens, ruptured in sodium with 0.25% oxygen, was somewhat greater than in the ruptured in air. The distinction of microstructure of these specimens from the preceding is concluded also in presence of a film of unknown composition the surface of specimen. This film is not stably connected.

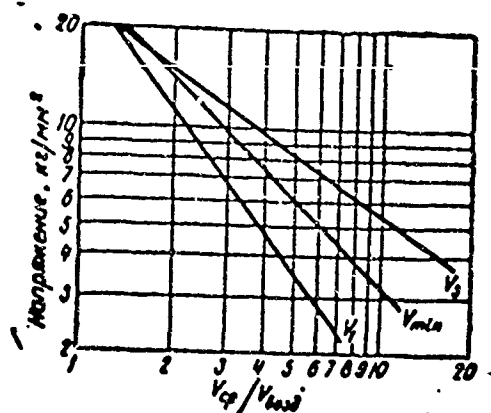


Fig. 3. Dependence on stress of coefficient of increase rate of creep (inner space) in sodium with 0.25% oxygen in comparison with air on first (v_1), second (v_{min}) and third (v_3) periods of creep. 1) Stress, kg/mm^2 ;

Evaluation of obtained results was derived by proceeding from the fact that, the effect of liquid-metal medium on metal in stressed state can be three forms: adsorption, corrosion and diffusion. In the general the final result is determined by these three effects. However, the effect of liquid sodium on steel is consequence of only corrosion and adsorption effects. Diffusion in this case is impossible in view of large difference in radii of atoms of iron and sodium. There were received experimental proofs of the absence of diffusion of sodium into steel. By spectrum analysis it was established that sodium exist in steel in an original state and that the aging of specimens in a liquid metal, containing 0.01 and 0.25% oxygen, during 500 hours does not give a change in the concentration of sodium either in the surface layer, or within the specimen.

The corrosion effect of liquid metal on hard metal may be result of action of one or combination of several following processes [9]: 1) dissolution of hard metal in liquid; 2) intercrystalline penetration of liquid metal into the hard; 3) formation of solid solutions and compounds between a hard and liquid metal; 4) interaction of hard metal with admixtures in the liquid metal; 5) thermal mass

transfer ¹; 6) isothermal mass transfer ².

In our case, the effect of sodium on steel could be realized only by means of dissolution of steel in liquid metal, of intercrystalline penetration of medium and by means of chemical interaction of elements, entering into the composition of steel, with oxide of sodium. It is known that solubility of main components of heat-resisting steels in sodium is small [1]. At the temperature in taking into consideration that volume of medium exerting an effect on specimen is small, it is impossible to expect a marked damage of specimen due to dissolution in liquid metal. This confirms results of test for stress-rupture strength in sodium with 0.01% oxygen and the metallographic analysis of the specimens.

The intercrystalline penetration of liquid metal into solid is associated with the solubility of solid metal and with the magnitude surface tension at the discontinuity solid-liquid metals. In work [10] it was reported that liquid sodium "moistens" chrome-nickel steel during temperatures at least higher than 200°. But, apparently, the size of marginal angle is nevertheless great. Therefore, and also because dissolution of steel in sodium is insignificant, intercrystalline penetration of sodium into steel was not observed.

Interaction of steel with oxide of sodium is still insufficiently studied. For us, important only is the fact that this form of corrosion causes a manifesting of additional defects on the surface of specimen.

Corrosion effect of medium on a metal under stress results in its premature rupture with small plasticity [11]. In literature there have not been reported cases of the acceleration of process of deformation in a medium, possessing only corrosion properties. The data, obtained by us, attest to a marked increase in rate of creep in sodium, saturated with its oxide, in comparison with the test in air. These data can be understood in the light of works by P. A. Rebinder

¹ Mass transfer, caused by difference of temperatures in various sections of the liquid-metal system and by dependence of solubility of components of constructional material in liquid metal on the temperature.

on the adsorption facilitation of deformation of solid bodies [12, 13].

Acceleration of creep in our case is the result of adsorption effect of a medium, which is significantly intensified by corrosion processes, which have increasing many fold the number of defects on the surface of specimen, which give rise to a plastic displacement. Confirmation of this is distribution of lines in Fig. 3. It shows that relative increase in rate of creep continuously increases with progress of process of creep, that is $K_{\sigma_1} < K_{\sigma_{min}} < K_{\sigma_2}$. ^{obviously/}corrosion causes continuous increase in number of defects on surface of specimen which, in turn, continuously intensifies the adsorption effect of liquid metal.

Thus, an acceleration of process of deformation can be by result of interaction of adsorption and corrosion factors. It is impossible to assume that increase in the rate of deformation and, in individual cases, an increase of plasticity wholly is determined by the adsorption properties of medium. As show the above-indicated results of experiments, the medium, not capable of a corrosion effect on steel (sodium with 0.01% oxide of sodium), cannot develop also an adsorption effect. This, certainly is valid only ⁱⁿ the case, if the medium possessed small superficial activity. If, however, the medium is a strong superficially-active medium and produces at the same time corrosion effect on deformable metal, then, obviously, also in this case the adsorption effects may be greatly intensified. Consequently, in an evaluation of the effect of a medium on metal under stress always it is necessary to consider, of what of component parts it is composed.

In literature there are no hints to the mutual strengthening of different effects in the reaction of a medium to a stressed metal. On the basis of described above results of experiment, it is possible to think that a reaction to a maximum

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Mass transfer, stipulated by presence on liquid-metal system of materials with nonidentical chemical composition.

degree will be manifested in the case, when a medium possesses adsorption, corrosion and diffusion properties. Obviously, the resultant effect will be then considerably greater than with a simple summation of the effects of the effect of a medium, capable only either of adsorption, or of corrosion, or of diffusion change of mechanical properties of a solid metal.

The interaction of adsorption and corrosion in our experiment/ with sodium, containing its oxide, was manifest, obviously, also in a more rapid development intercrystalline cracks, which result on the rupture of the steel. The adsorption action of the medium and corrosion damage of the metal in crack together gave an earlier rupture of specimens, than in air.

In returning to an evaluation of the effect of oxygen, contained in the sodium, on the stress-rupture strength of steel one should note that the presence of at least 0.01% oxygen in liquid metal does not result in a premature rupture. The difference of our results from results of corrosion tests is explained, apparently as follows. Usually corrosion tests are conducted in circulation loops, having a temperature drop over its entire length. As it was shown by Horsely [14], with a reaction on iron of sodium, containing oxide, there occurs a formation on surface of the film of the compound $(Na_2O)_2FeO$; the film dissociates at a low temperature. This film is not durably bound with the surface, consequently, can be washed away by flow of liquid metal, to be transferred to the cold sections of the loop and there to dissociate. Liberated oxide of sodium after this again is capable to react on a solid metal. It is obvious that under such conditions there must occur an incomparably greater corrosion rupture of the metal than in ours. It is possible, a great influence on the stress-strength of steel is exerted by sodium, sodium contaminated by oxide, in the case, if a steel is less inclined to intercrystalline rupture in air.

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